ROBOTIC SURGERY AS A NEW BRANCH IN CARDIOVASCULAR SURGERY

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Medicine changes with an ever increasing pace, and cardiovascular surgery is not an exception: introduction of minimally invasive techniques revolutionized the surgical practice (1, 2). As minimally invasive approaches to cardiac surgery expanded, wide acceptance of off-pump techniques of coronary artery revascularization entered the zone of computer telemanipulations, one-shot anastomoses, and valve faceting devices. Recently, robotic instrumentation has been introduced into the operating room. The robotic systems directly assist and enhance a surgeon's performance. Robotic surgery is a sophisticated technological method carried out automatically by using a robot to move the surgical tools under position control. The surgeon performs the procedure while watching the operation on a monitor.

The development of endoscopic coronary artery bypass grafting has been limited due to poor visualization and increased technical difficulties in carrying out operations through ports. The use of conventional endoscopic instruments results in an inaccurate and time-consuming performance due to limited range of motion. Video directed two dimensional (2D) anastomosis required multiple port sites. However, three dimensional (3D) visualization significantly improved video dexterity in performing the coronary anastomosis. Sophisticated robotic engineering developed assisted endoscopic instruments to minimize these difficulties by robotic telemanipulation and 3D visualization technology. The dexterity of the robotic articulation wrists permits variation of needle angles. Robots designed for surgery have main advantages over humans: they have greater three-dimensional spatial accuracy and can achieve greater precision under direct surgeon control. With robotically-assisted microsurgical instrumentation, a completely endoscopic anastomosis of LITA to the LAD is possible, allowing a technologically performed endoscopic coronary bypass grafting (E-CABG) within acceptable time limits.

The current studies demonstrated that coronary artery bypass grafting on cadaver, animal and even on arrested or beating heart is technically feasible with a robotically assisted microsurgical system (3-6).

INSTRUMENTATION

Robotic systems consist of three main components: a surgeon interface device, a computer control and special instruments attached to robotic arms. Robotic devices have been designed and developed in laboratory.

The ZEUS™ Robotic Surgical System (Computer Motion) consists of three interactive robotic arms and a control unit, allowing the surgeon to move the instrument arms in a scaled down mode. (Figure 1) Two of these arms are directly attached to the operating table. The surgeon controls the instruments by manipulating specially designed handles. These surgical controls allow for four full ranges of motion (pan, roll, tilt, and in/out) as well as grasping. The surgeon's motions are directly and precisely translated into the robotic arms by a sophisticated computer control. (Figure 2) While seating at the console, the surgeon views the operative site with a high-resolution monitor and operates handles which resemble conventional surgical instruments. The third arm (AESOP, Computer Motion) which positions the endoscope is directed via voice control. With voice commands, the surgeon controls the movements of endoscope and changes the view of the video monitor. The surgeon's hand movements are scaled and tremor is filtered through the custom-designed software and translated via the robotic arms into precise micro movements at the operative site. With precise and consistent movements, AESOP provides the surgeon with direct control of a steady view of the operative field. HERMES (Computer Motion) is a platform enabling surgeon to directly control endoscopic equipment with simple verbal commands. HERMES allows the use of multiple compatible networked devices in

Figure 1. The ZEUS™ robotic surgical system.

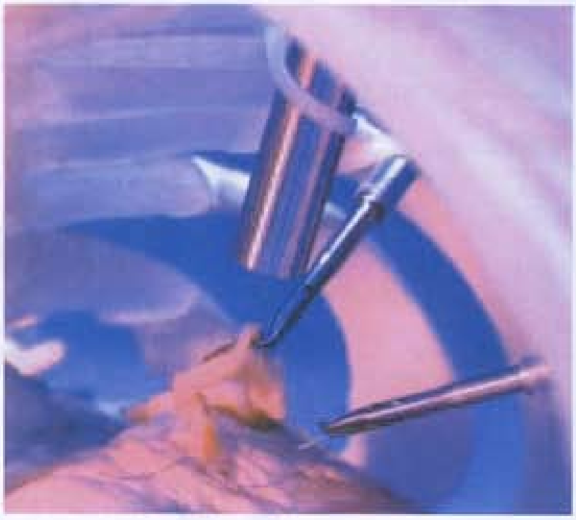

Figure 2. The robotic arms of ZEUS™

Figure 3. Endo Wrist™.

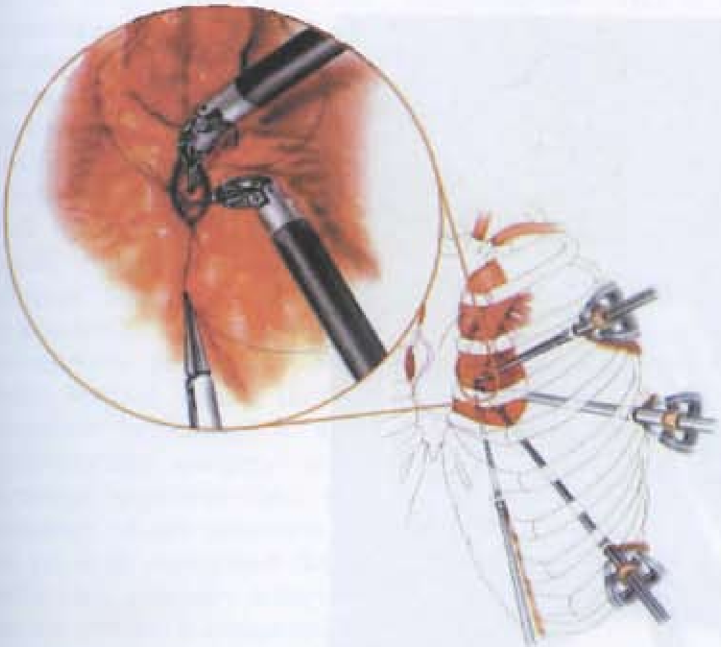

Figure 4. The introduction of the robotic assists through three ports.

operating room, such as tables, lights, cameras and surgical equipment through a centralized computer control unit. These HERMES-Ready devices can be controlled by simple voice commands or via a pendant hand-held touch-screen the operative field.
The Intuitive™ System is designed to translate surgeon's instructive hand movements performed outside the body into precise micro-movements in the mediastinum through the use of a mechanical wrist. A robotic wrist, EndoWrist™ provided articulated motion with a full 7 degrees of freedom of motion inside the chest cavity. (Figure 3) The robotic assists which consist of 3D endoscopes and instruments are introduced into the left side of the chest through three intercostal ports. (Figure 4) Natural forearm and wrist movements are replicated in the surgical field using detachable instruments. (Figure 5)

CLINICAL TRIALS

Current studies provide encouragement that robotic assistance brings a technology that will allow the development of endoscopic coronary artery bypass grafting.
Carpentier and Loulmet reported the first robotic cardiac operation in 1998 (4). They performed an atrial septal defect closure and a mitral valve repair using robotic surgical procedures (5). Later Mohr and Falk performed mitral operations (2) and first robotic coronary anastomosis, through an open incision. Both groups used "daVinci" (prototype) and "EndoWrist™ " of the Intuitive System (Intuitive Surgical).
Loulmet and Carpentier, from Broussais Hospital, reported the first clinical application of robotic surgery in coronary artery bypass surgery in four patients using the Intuitive System. Robotic 3-dimensional endoscopes and instruments were introduced into the left side of the chest through 3 intercostal ports. The Heartport system was used for arresting the heart during the anastomosis. In two patients, harvesting of the left internal thoracic artery was completed endoscopically with robotically-assisted instruments and anastomosis to the left anterior descending artery was performed by minithoracotomy with conventional instruments. The harvesting time of LIMA was 78 ± 13 minutes. In the other two patients, the entire operation was completed endoscopically with robotic assistance. The completion of the endoscopic anastomoses took 18 and 32 minutes. Cardiac arrest lasted 47 and 65 minutes. It was reported that the grafts were patent on early

Figure 5. The Intuitive ™ System.

postoperative coronary angiography without any symptoms in all cases (6).

Mohr and Falk, from University of Leipzig, reported their experience on 129 patients with non-ischemic mitral valve disease who underwent 3D-video assisted mitral valve surgery via a 4 cm right lateral minithoracotomy using femoro-femoral bypass and endoaortic clamping (2). The mitral valve was repaired in 72 and replaced in all other patients. After the initial series (group I, n=62), a simplified solo surgical technique using voice-controlled robotic assistance for videoscope guidance was used in the other 67 patients (group II). In these 67 patients, the procedure was completed as 'solo surgery' without any need for an additional assistant.

Reichenspurner and Damiano, from Hershey Medical Center, reported their initial experience on robotically-assisted E-CABG at International Society for Minimally Invasive Cardiac Surgery's 2nd Annual Meeting and Scientific Sessions, Paris, France, on May 21-22, 1999 (7). They performed robotically-assisted LITA to LAD anastomosis using interactive robotic arms and voice-controlled camera guidance in a phantom model, in 6 dogs and in two patients (8). Two patients were operated on with the ZEUS and Port-Access endovascular cardiopulmonary bypass system. In these cases, preparation times for the LITA were reported as 83 and 110 minutes and anastomosis times were 42 and 40 minutes. Doppler flow rates were measured as 125 and 85 ml/min. It was reported that the patients had an uneventful postoperative course and follow-up angiogram.

DISCUSSION

The future of coronary artery surgery will be based on minimally invasive techniques, full arterial revascularization, and selective lipid modification to reduce progressive atherosclerosis (7).

As it is in most of the technological improvements, for minimally invasive techniques as well, after experimentation; comes the phase of the learning curve, improvement in surgical tools, then the analysis of outcome and comparison with the standard methods. Hence, currently there is the need for clinical trials on these techniques, ideally independent from the industry, to validate each of the newly advocated approaches, comparing them with conventional procedures. Recently, The Wall Street Journal raised the issue of whether premature launching of new technology in cardiovascular surgery was beneficial (8). However, objective data to substantiate the advantage of one approach over another have not yet been elucidated. Thus, the goal of an endoscopic coronary artery bypass procedure has not yet been completely established, and will require further technological advances and experimentation.

Formerly, endoscopically sutured anastomoses were very difficult to perform due to the size and imprecision of standard endoscopic instruments (9). But, current robotically-assisted systems are able to eliminate tremor and allow the performance of an endoscopic anastomosis with precision. While performing endoscopic anastomosis, appropriate port placement and orientation relative to the left anterior descending artery can have paramount impact on success and ease of the procedure.

Gundry and associates have reported that patients who had minimally invasive direct coronary artery bypass grafting required twice as many repeated coronary angiograms, and in these, graft patency was half that of patients who underwent conventional cardiopulmonary bypass (10).

However, according to Koşuyolu Heart and Research Hospital's experience, when minimally invasive direct coronary artery bypass grafting and beating heart techniques were compared with conventional CABG, no statistically significant difference was found (11).

The cost of minimally invasive techniques is staggering and hinders wide acceptance of these technological improvements. Actually, this is of concern with respect to many other devices that are not reusable.

Although, the use of minimally invasive techniques in general, and robotic surgery in particular, is still a controversial issue, they have a prominent role in the improvement of cardiovasculat surgery; and it seems that they will pave the way for development of endoscopic coronary artery bypass grafting.

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